Using Radiative Transfer Calculations to Assess Limits for the Retrieval of Surface Irradiance Components from Satellite Information

Hans Georg Beyer
Department of Electrical Engineering
University of Applied Sciences (FH) Magdeburg, D-39104 Magdeburg, Germany
Phone/Fax +49-391-16499/16126,
E-mail hans-georg.beyer@elektrotechnik.fh-magdeburg.de

Detlev Heinemann
Department of Energy and Semiconductor Research, Faculty of Physics
University of Oldenburg, D-26111 Oldenburg, Germany
Phone/Fax +49-441-798-3543/3326, E-mail dehe@ehf.uni-oldenburg.de

Calculation schemes for the radiative transfer in the atmosphere offer a tool to assess the possibilities for the retrieval of detailed information on the irradiance from satellite signals. For this purpose we applied the MODTRAN code, a reference for the simulation of the atmosphere-radiation interaction.

MODTRAN was used to test the influence of atmospheric conditions on both the direct and diffuse components of solar surface irradiance and the outgoing flux as seen by sensors of a satellite. This reveals information on the coupling of the different fluxes. From this information, the limits for the inference of the ground data from the satellite signal at different wavelength bands and from additional information on the state of the atmosphere (i.e. typical aerosol and water vapor content) may be derived.

We will present results for both clear sky and over-cast situations. It is shown that visible channel informa-tion alone is not sufficient for an exact calculation espe-cially of the downward diffuse flux. The possible contri-bution of theinfrared channel for adding information for both clear and cloudy skies is assessed. In this context we will also briefly point out the problems arising from the existence of broken cloud fields.

The presentation concludes with an short outlook on options resulting from the use of next generation sa-tellites offering sensors with an improved wavelenth resolution.

Subject:

Radiative transfer models may be used to analyse
the influence of the physical properties of the atmosphere
on

- downward radiation at ground level

and

- (backscattered) radiation as registered by the satellite sensor

This gives information on the strength of

- the link satellite signal (visible + infrared) ⇔ irradiance at ground level

and

- possible need for additional data.

Radiative transfer calculations

Interaction radiation $\leftrightarrow$ atmosphere

Basic processes:

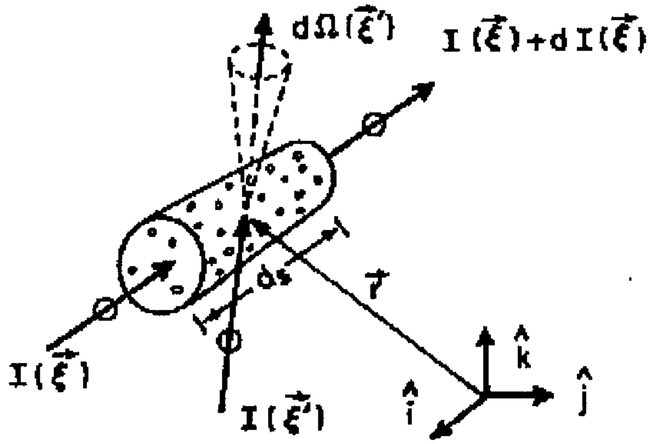
- scattering
- absorption
- emission (for infrared radiation)

by:

- air molecules
- aerosols
- water vapor
- water droplets (microscopic)
- cloud geometry (macroscopic)

Scattering

scheme for radiative flow through a volume element:



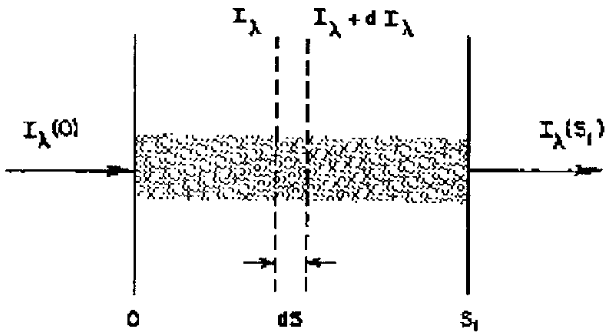
main active constituents:

- air molecules
- aerosols
- water vapor
- cloud droplets

to be described by their

- quantity
- geometry
- directional scattering properties
  (Rayleigh, Mie)

Absorption



main active constituents:

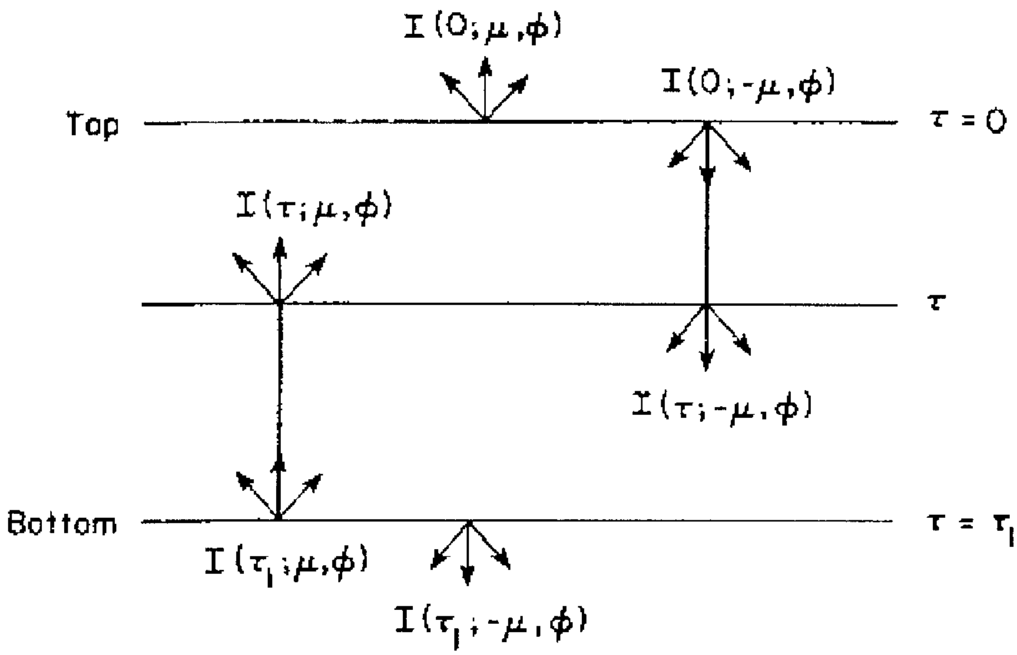
- water vapor
- aerosols
- liquid water

described by their quantity

Radiative Transfer in the Earth Atmosphere

upward (to satellite) and downward (radiation at ground level) intensities

scheme: plane parallel atmosphere



Tools:

MODTRAN

- state-of-the-art for clear atmosphere
- based on detailed molecular absorption data base
- not specialized for cloudy atmospheres
  - two-stream approximation
  - limiting assumptions in case of multiple scattering
  - only in recent version more sophisticated assessment)

- therefore not optimal for radiance calculations
  ok for flux calculations

SBDART

- more specialized in simulation of satellite signals
  (i.e. good representation of radiances)
- more 'screws' for changing cloud properties
- better modeling of cloud-radiative interaction

both are highly time consuming

alternative: pre-calculation of look-up-tables for a set of geometry-atmospheric state parameters

Aim

use radiative transfer models to analyse the relationship between

radiance as seen by the satellite

and

downward surface irradiance

necessary inputs:

data on

- temperature profile
- aerosols, water vapor (profiles)

  $\Rightarrow$ visibility, (turbdity)

- water content of clouds, drop size

  $\Rightarrow$ optical thickness, liquid water path

Conclusion

influence of turbidity on downward irradiance (especially the diffuse component) is only poorly reflected in the satellite signal

Additional use of the infrared (IR) signal ?

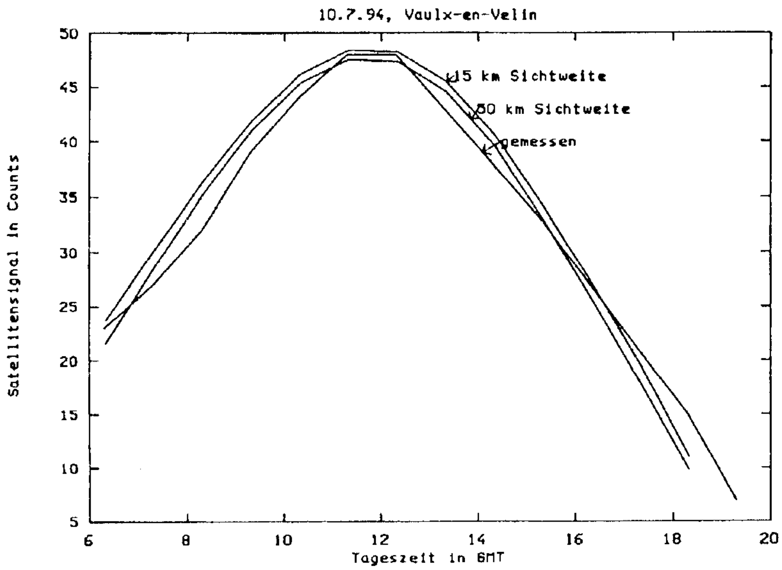
⇒ IR signal gives only little information on turbidity (influence of the (unknown) ground temperature is more prominent

⇒ need for more ground based information on turbidity

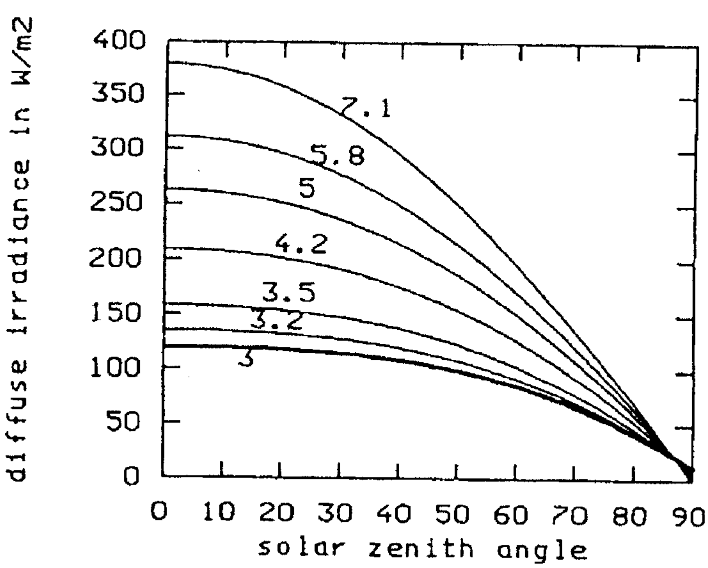
1. Clear Sky

clear atmosphere, variation of **turbidity (visibility)**

satellite signal 50°N, June; parameter: visibility



diffuse irradiance at ground level (parameter: turbidity)



2. Overcast Sky

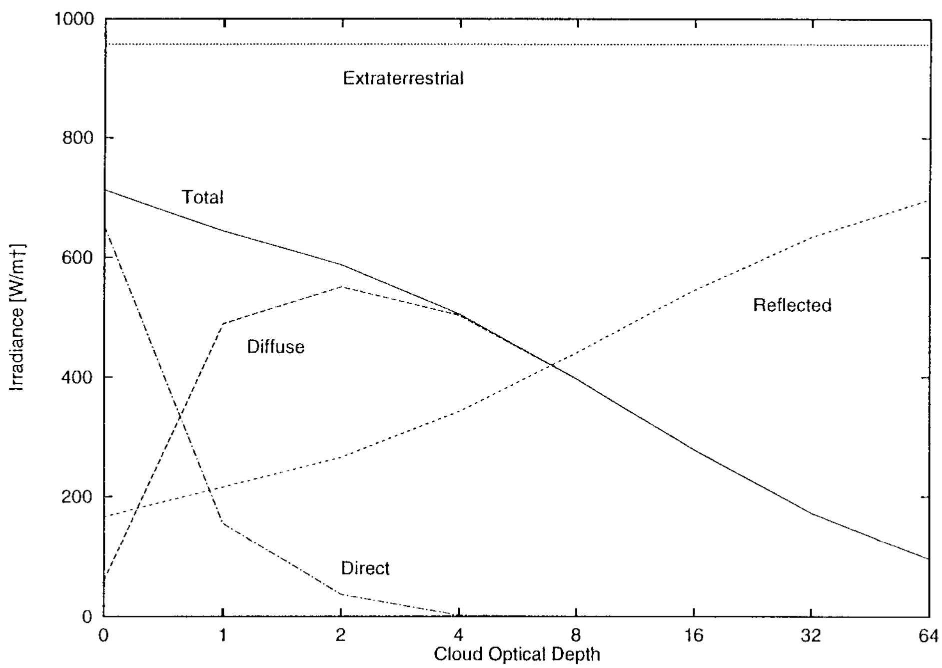
cloudy atmosphere, variation of the optical thickness of clouds

here: only homogeneous cloud cover

cloud characterized by:

- optical depth, droplet size
- cloud height

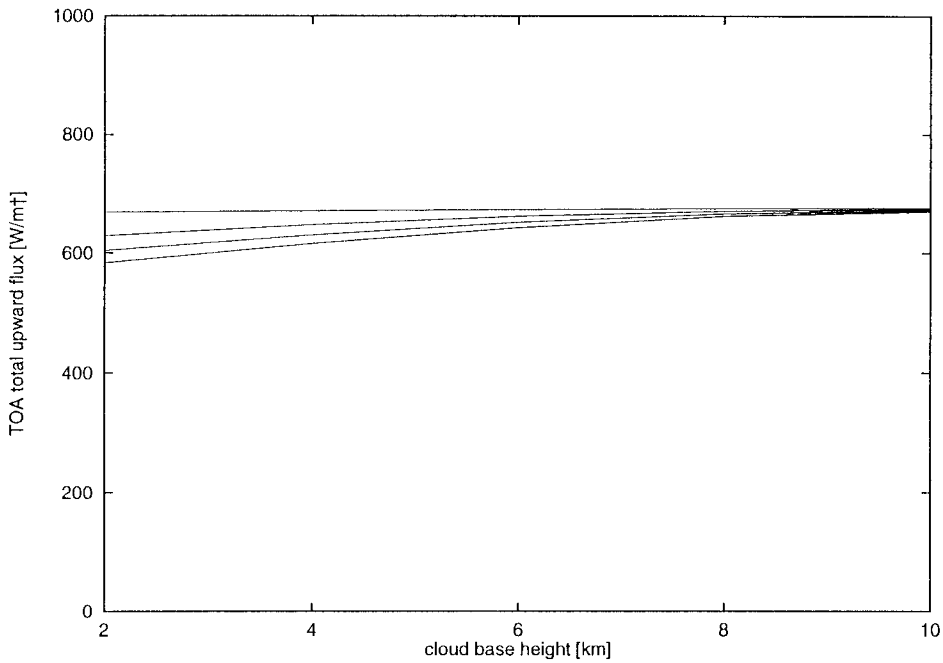
upward and downward flux as function of cloud optical depth:



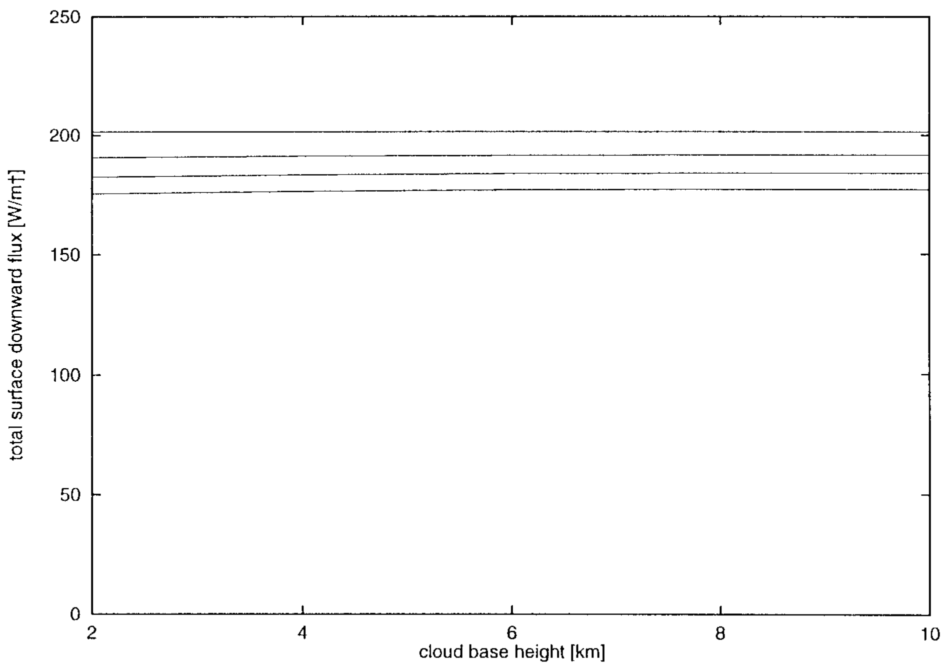
variation of downward and upward flux with cloud base height

(optical depth: 32)

upward:



downward flux:



Conclusion

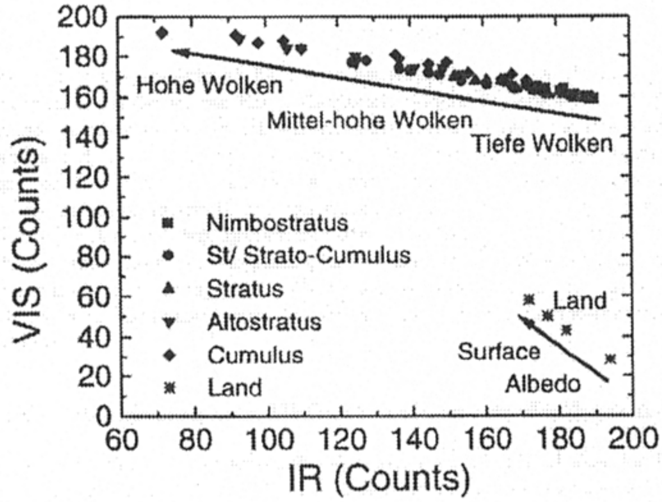
optical thickness has the dominating influence on both the VIS signal and the diffuse radiation at ground level

minor effects: cloud height, size distribution of droplets

3. Broken Clouds

evidence:

relation of VIS and IR signal for overcast and clear sky from radiative transfer model:

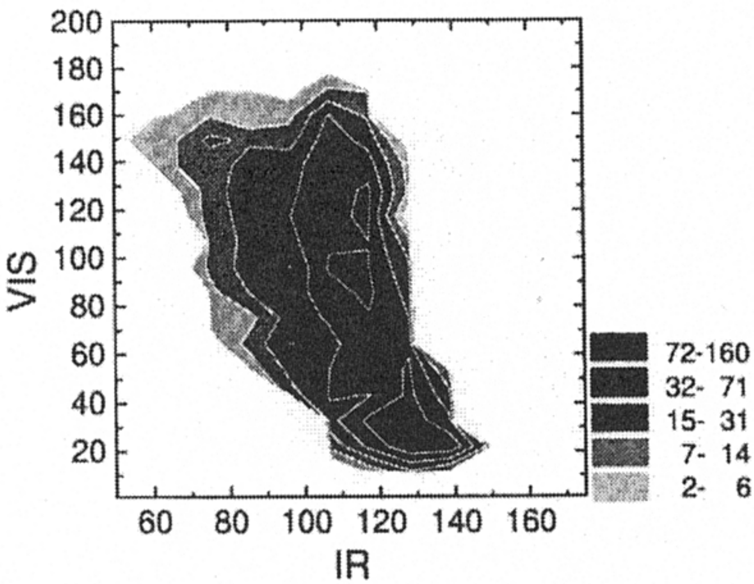


high

medium high

low clouds

empirical relation :



⇒ for a spatial resolution of 10 km x 10 km intermediate (broken cloud field) conditions are prominent simple approach to deal with broken clouds:

independant (sub)pixel assumption

- satellite signal is the mean signal from independant subpixels
- each subpixel is either cloudy (parmeter: cloud optical thickness) or clear
- cloud fraction determines mix of pixels cloudy and clear

$\Rightarrow$

both VIS and IR signal are effected by the product of optical thickness and cloud fraction

IR signal additionally sensitive to the (unknown) cloud top height

$\rightarrow$ cloud fraction can not be gained from the VIS and the IR signals

Conclusion: even with the independant pixel assumption the diffuse to direct ratio (for broken cloud flields governed by the cloud fraction) is not strongly linked to the satellite signal for the respective pixel

Remark

From Monte Carlo simulations it is known, that the independent pixel assumption is only of limited validity

cloud field reflectance and absorptance are influenced by its morphology (given by e.g. its fractal characteristics)

$\Rightarrow$ the macroscopic geometry of the cloud field introduces additional unknown parameters to the problem

Areas for Further Research

Interference of pixel cloud fraction from multiple pixel characteristics
(evidence: successful empirical methods to link diffuse fraction with hourly variations of surface irradiance)

tool: use of ground-based cloud imagery
irradiance data with high time resolution

→ use of scaling properties of the cloud field to derive subpixel characteristics ?